

THE MODULATION OF OPTICAL PROPERTIES OF SOMBRERO KEY, FLORIDA

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ABSTRACT

A study of the optical properties of Sombrero Key reef was made from 28 June to 1 July 1997. The attenuation coefficient at 440 nm of the color constituents of water near Sombrero Key was dominated by scattering ($b = 0.19 \text{ m}^{-1}$) while constituent absorption at 440 nm was only 0.07 m^{-1} . The high $b:a$ ratio is possibly the result of re-suspension of sediment by wave action. The constituent absorption value ($a(412) = 0.25 \text{ m}^{-1}$) in Hawk Channel, between Sombrero Key reef and Florida Bay, was much greater than on the adjacent reef ($a(412) = 0.07 \text{ m}^{-1}$). This warm, saline, particle-rich water appeared to be trapped at depth in the channel as a result of higher density (1022.6 kg m^{-3} vs. 1022.4 kg m^{-3}), ultimately flowing out through cuts in the reef rather than over the reef top. The $a_g(412)$ values were 85% of the constituent absorption coefficients over Sombrero Key Reef while it contributed only 65% to constituent absorption for Hawk Channel. The relatively high $a_g(412)$ values (e.g. 0.06 m^{-1}) found over the reef may aid in limiting UV penetration to the coral at depth ($> 8\text{m}$) and may limit possible UV effects on coral bleaching.

INTRODUCTION

The development of the South Florida region has brought changes in the local coral reef ecosystems. Fresh water passed through the Everglades into Florida Bay prior to development of this area. The water from Florida Bay flowed out over the coral reef regions during rainy periods. Containment of water in Water Conservation Areas and diversion of water for urban use and flood control have limited the fresh water input into Florida Bay. Florida Bay regularly becomes hypersaline during periods of low rainfall (McIvor et al., 1994). Smith et al. (1989) studied the banding produced on a large coral head by humic substances outflowing over the Florida Reefs. They determined that there was a marked decline in the outflow from Florida Bay over the reefs starting in about 1932.

The Florida reef system near Sombrero Key was selected for study to characterize the area's optical properties. Water out-welled from Florida Bay over Sombrero Key may have, in year past, attenuated the ultraviolet wavelengths that could harm the corals. Because of the dynamic environment of coral reefs, winds and tides are expected to have some influence on the optical properties of the reefs.

The measurement of optical parameters on coral reefs has not been attempted until recently. The low light attenuation of the waters in the ecosystem requires sensitive instrumentation. The use of inversion models of Rrs to determine water properties has

been hindered by the bottom albedo from the reef itself. Advances in instrumentation and modeling techniques have made the determination of coral reef optical parameters possible.

Methods

The stations visited were on a line from Vaca Key to the Florida Current (Figure 1). The instruments used for sampling were 2 WET Labs, Inc ac-9s and an FSI CTD. Both ac-9s were configured to measure absorption ($a(\lambda)$) and attenuation ($c(\lambda)$) at wavelengths of light centered at 412, 440, 488, 510, 532, 555, 650, 676, and 715 nm. The units were calibrated and deployed using the techniques suggested by the ac-9 Protocol Manual (1996). One ac-9 was fitted with a filter of 0.22 μm pore size to measure dissolved organic matter absorption ($a(\lambda)_{\text{CDOM}}$). Scattering ($b(\lambda)$) was calculated by subtracting absorption from attenuation. The ac-9s were calibrated using dionized water and the $a(\lambda)$, $a(\lambda)_{\text{CDOM}}$, and $b(\lambda)$ presented in this paper represent the constituents without the absorption of water.

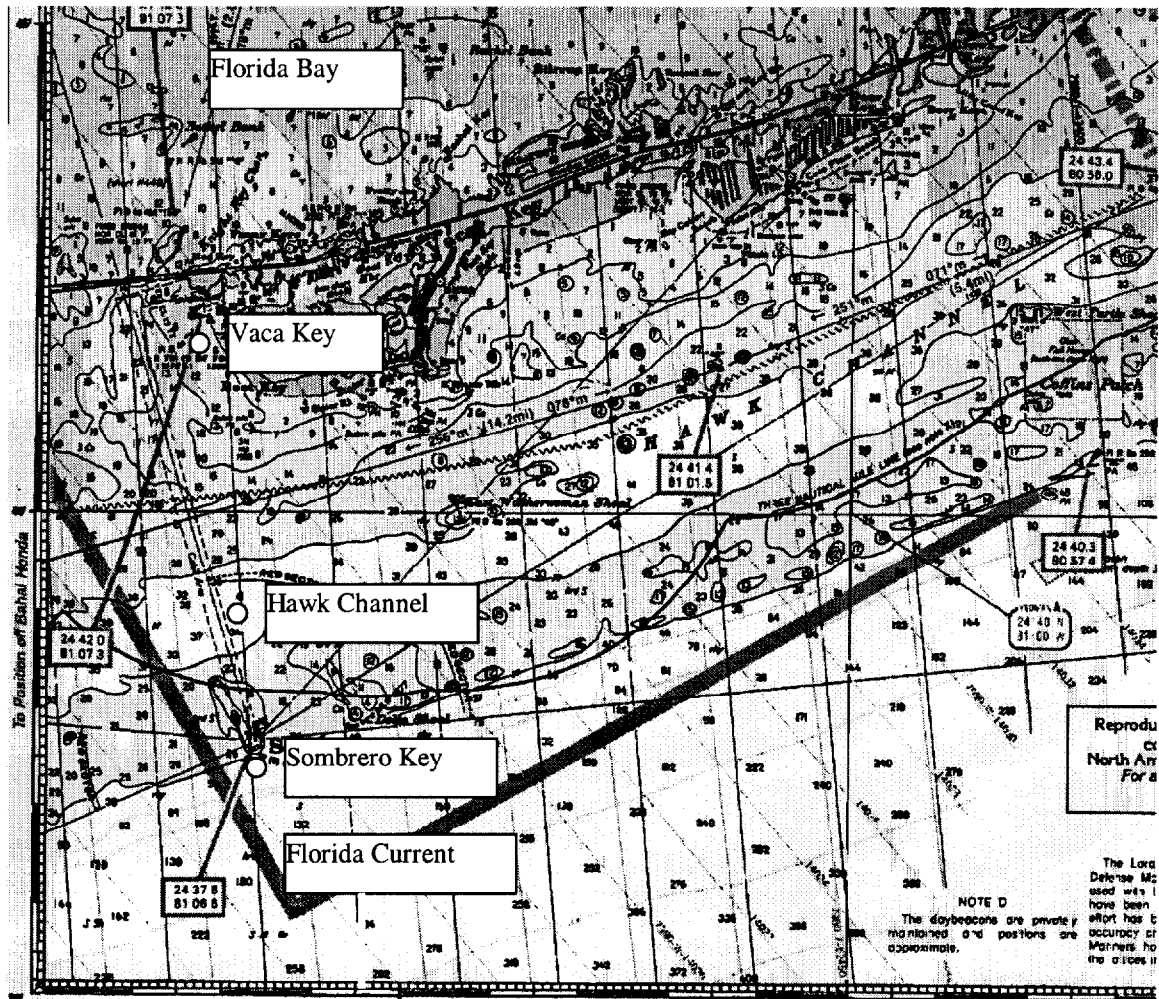


Figure 1. Stations Sampled During the Study. Locations are marked by the name of each station and a white dot. The Florida Current station is not shown on this map.

Meteorological data was obtained from the NOAA C-MANS station located in the lighthouse on Sombrero Key. Tidal information was obtained from the NOAA tide gauge located on Vaca Key. An archive of the data is maintained at the URL, “<http://www.nws.fsu.edu/buoy/>”.

RESULTS

The IOPs on the reef were compared against tidal height to determine the effect of physical parameters on the optical properties. The sinusoidal shape of the curve of particulate scattering values at 412 nm plotted against tidal height suggests a maximum ebb tide current influence at 0.318 m (Figure 2). Sediment was likely suspended at maximum cbb tide. The wind speed was low ranging from 4.6 m s^{-1} to 5.6 m s^{-1} and considered to have negligible influence.

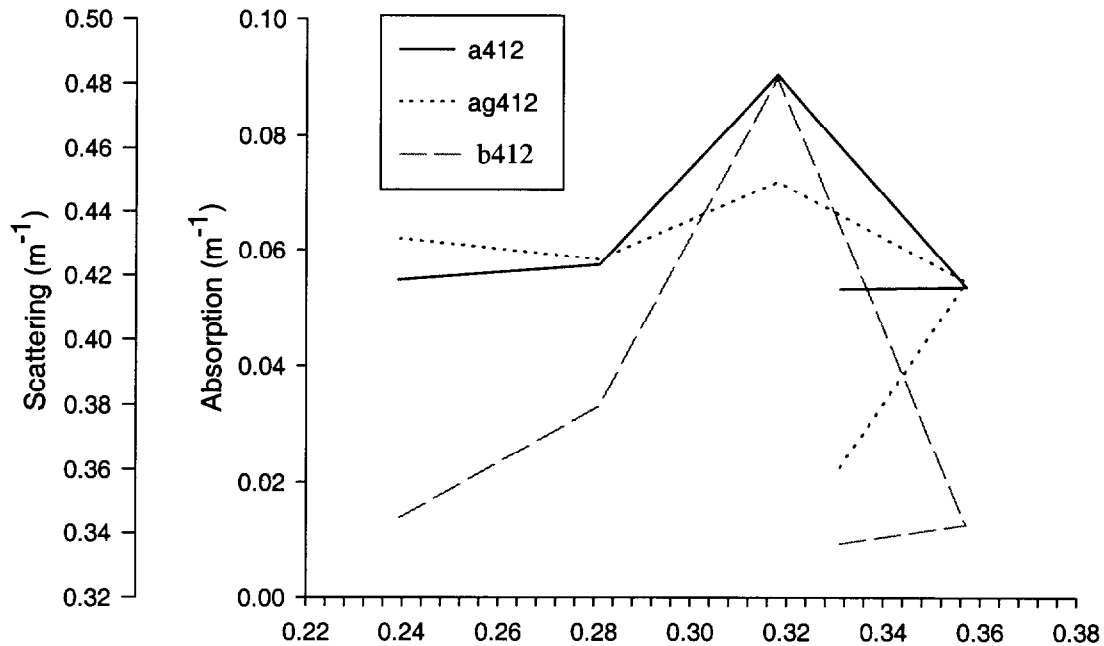


Figure 2. Tidal Influence on Optics on Sombrero Key Reef. The absorption and scattering values have no clear relationship with tides during the period sampled.

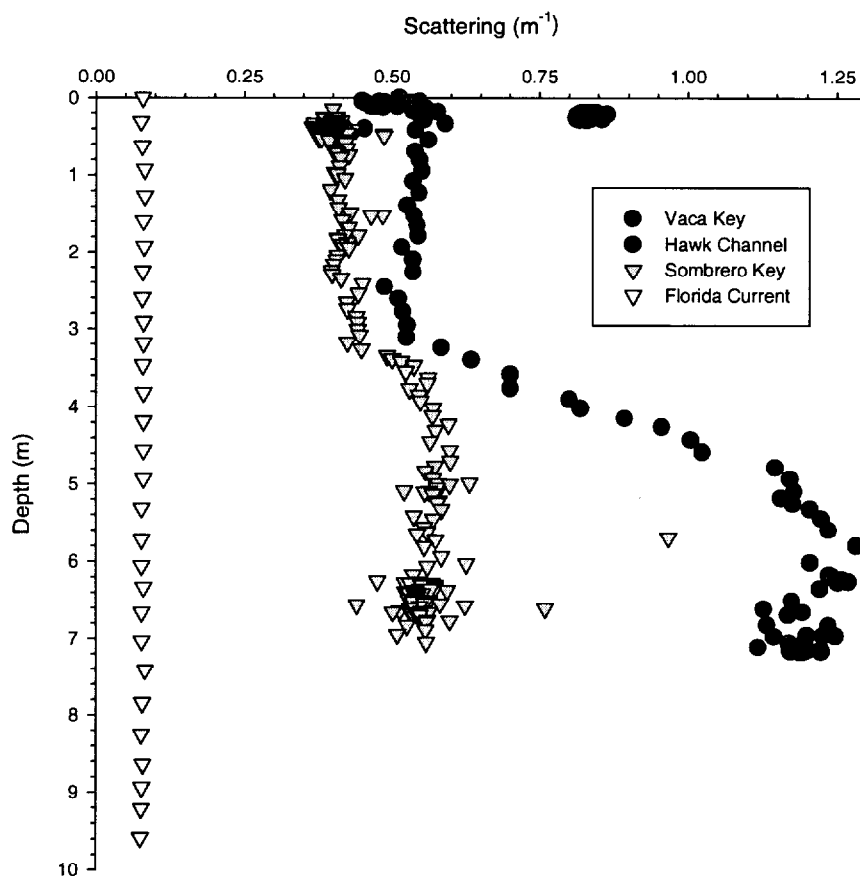


Figure 3. Scattering at 412 nm over Depth for the Stations Occupied. The Hawk Channel Station exhibits the greatest variation in scattering over depth. The Sombrero Key Station exhibits some increase in scattering at depth.

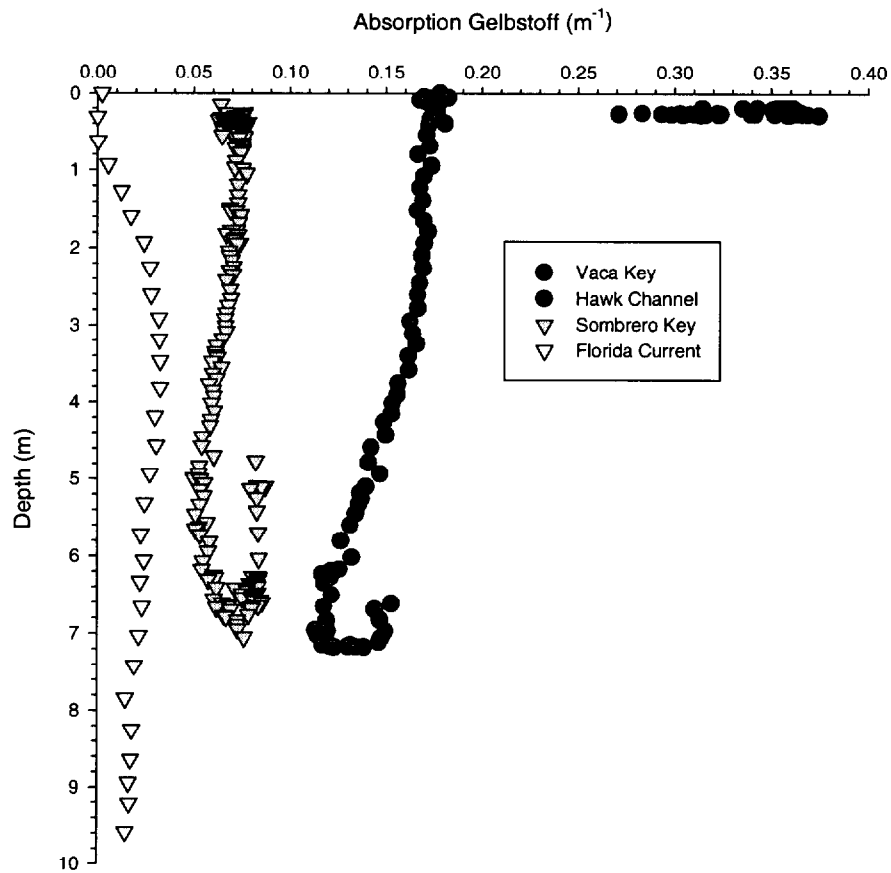


Figure 4. Gelbstoff Absorption at 412 nm over Depth for the Stations Occupied. The Vaca Key station exhibits the highest gelbstoff absorption values.

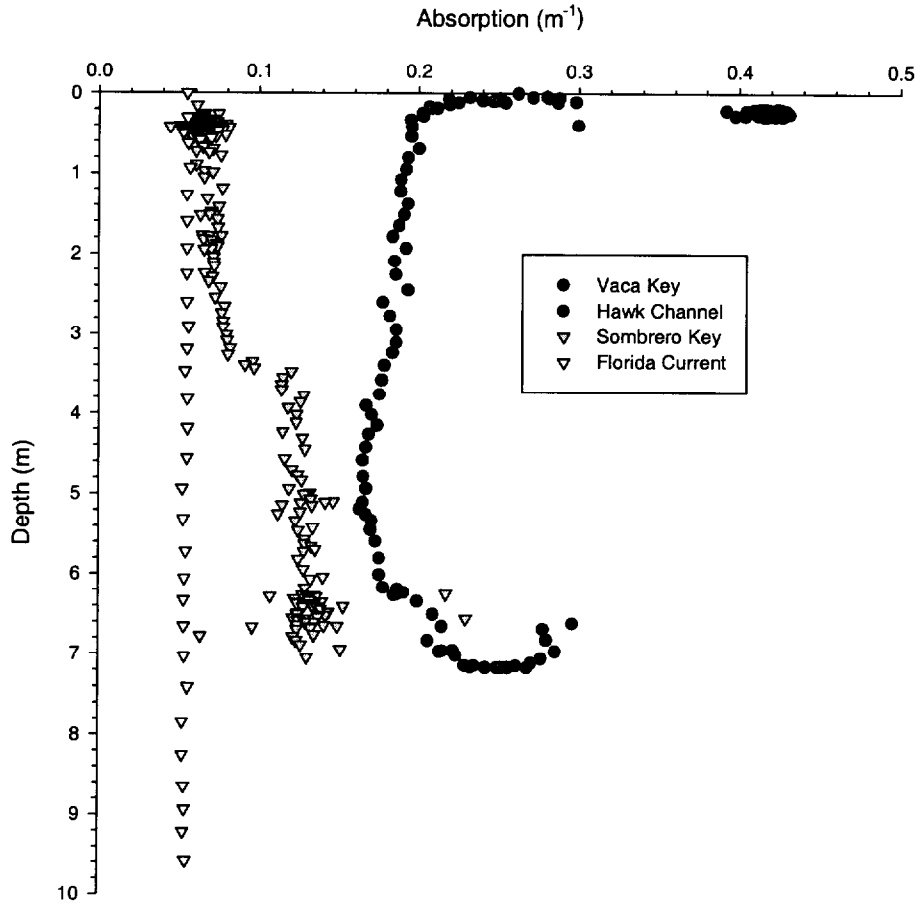


Figure 5. Absorption at 412 nm over Depth for the Stations Occupied. The Vaca Key station shows the highest absorption values. The Hawk Channel and Sombrero Key stations increase in $a(412)$ at depth.

The scattering increased with depth for both the Hawk Channel and Sombrero Key (Figure 3). The $a(412)_{\text{CDOM}}$ values did not exhibit as distinct a pattern over depth as the scattering or absorption values (Figure 4). $a(412)_{\text{CDOM}}$ decreased over depth for the Hawk Channel Station. $a(412)$ had a trend of increasing with depth for Sombrero Key and Hawk Channel (Figure 5).

The $a(412)$, $a(412)_{\text{CDOM}}$, and $b(412)$ were compared for different locations sampled during the cruise. The values showed differences in magnitude between stations and relative to one another at each station. The Sombrero Key Station was occupied from

1138 to 1604 EST on 6/29. The variability in the mean values during this period was $\pm 35\%$ for the absorption values, $\pm 22\%$ for the scattering, and $\pm 27\%$ for the a_{CDOM} . The percentage of a_{CDOM} to absorption during the periods sampled was 84% for Sombrero Key, 71% for Hawk Channel, 59% for Vaca Key, and 25% for the Florida Current. The b/a ratio for each area was 5.85 for Sombrero Key, 3.92 for Hawk Channel, 3.12 for Vaca Key, and 1.37 for the Florida Current.

The station in Hawk Channel was located approximately 4 km North of Sombrero Key. There were differences in the salinity and temperature profiles between these two stations (Figure 6). Hawk Channel had a higher salinity and temperature at depth. The deeper Temperature and Salinity values at Hawk Channel are similar to the values for the station at Vaca Key (30.62 °C and 36.39 ‰ salinity). The salinity increases by 0.12 and the temperature decreases by 0.13 °C over depth at Sombrero Key. The salinity increases by 0.24 ‰ and the temperature increases by 0.24 with depth in Hawk channel. The Hesselberg stability index had a value of 0.0338 for Hawk channel indicating stratification between the upper 3 meters and depth. Sombrero Key had a value of 1.92×10^{-6} indicating a well-mixed water column.

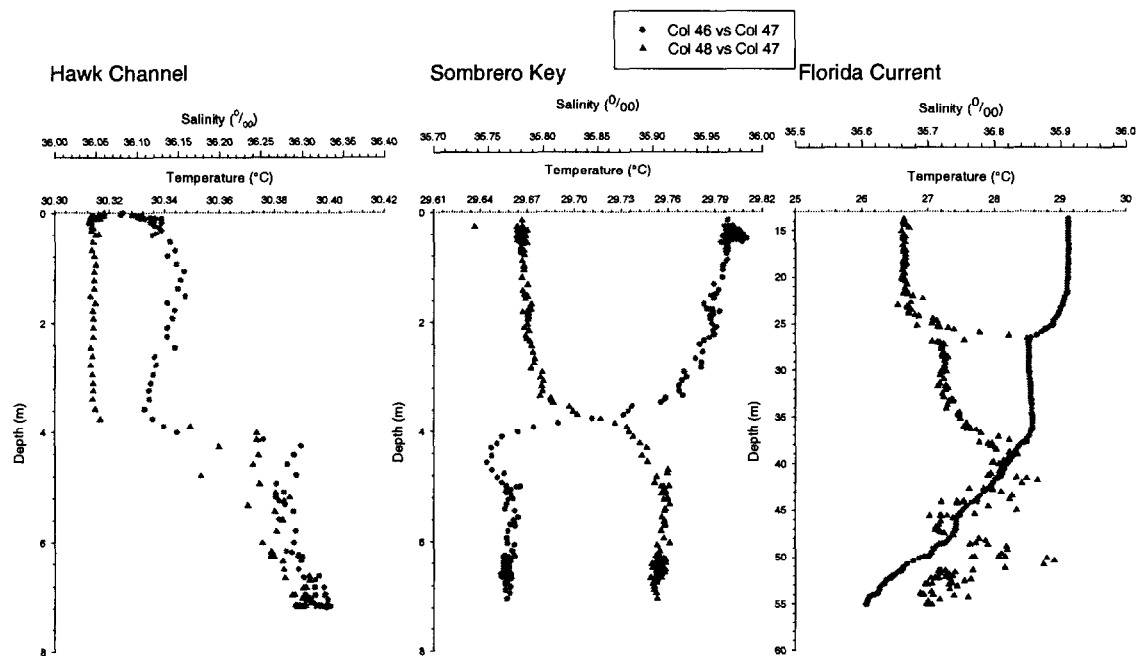


Figure 7. Temperature and Salinity Profiles from Hawk Channel, Sombrero Key, and the Florida Current. The salinity and temperature at Hawk Channel is higher. The temperature and salinity for Hawk channel follows the same pattern over depth while

the temperature and salinity for Sombrero Key follows an opposite pattern over depth. The values for Sombrero Key are similar to the surface values for the Florida Current.

DISCUSSION

The tides were hypothesized to transport higher attenuation water from Florida Bay over Sombrero Key. The outwelling due to the tides was not observed in the optical data and the physical parameters. Only the apparent local resuspension of sediments during maximum ebb is manifest in the optical properties. The b to a ratio indicates that scattering is much higher relative to absorption in the water over Sombrero Key as compared to the other locations. The $a(\lambda)_{\text{CDOM}}$ to $a(\lambda)$ ratio was the highest over Sombrero Key as compared to the other areas sampled. The relative values of the constituents contributing to attenuation at Sombrero Key indicate that the outwelling of water from Florida Bay did not influence the water over Sombrero Key.

The differences in optical properties at each area sampled reflect the nature of each environment. The absorption values at Vaca Key probably reflect the resuspension of particulate organic matter, terrestrial influences, and outwelling from Florida Bay. The $a(\lambda)$ value at Sombrero Key was dominated by $a(\lambda)_{\text{CDOM}}$. Based on the low $a(\lambda)_{\text{CDOM}}$ values from the Gulf Stream station and the higher values at the Hawk Channel Station, the CDOM appears to be produced on the reef.

The Vaca Key station had a spectral slope coefficient for CDOM of 0.0174 nm^{-1} while Sombrero Key station had a spectral slope coefficient for CDOM of 0.0213 nm^{-1} . The larger slope coefficient on the reef may indicate a higher proportion of fulvic acid absorption in the CDOM. Fulvic acid is considered to be more recently produced material, while humic acid is considered a possible break down product of fulvic acid. (Carder et al., 1989). Corals may produce a UV-light-absorbing mucus under certain conditions (Drollet et al., 1993). Corals may emit peridines and flavines into the water column (Chen and Bada, 1992). Organic compounds produced by corals may be the source of the CDOM on Sombrero Key reef.

The denser water in Hawk ($\rho(s,t,p) = 1022.60 \text{ kgm}^{-3}$) channel may originate from Florida Bay. The temperature and salinity signatures seem to indicate that it is from there. The hypersaline conditions within Florida Bay result in denser water that flows out along Hawk Channel and may never reach the shallower Sombrero Key Reef. The higher gelbstoff in these waters may have once protected the reefs from UV bleaching.

The higher attenuation at depth is the opposite from the expected paradigm of estuarine outflows. The higher attenuation water in most estuarine environments is usually less saline and lower density than oceanic water. Estuarine water typically floats on the top of the oceanic water but it sinks below them in Hawk Channel. The turbid water at depth in this region may result in interpretation of a shallower bottom when remote-sensing reflectance algorithms are applied in this area.

CONCLUSIONS

The Sombrero Key Reef has optical properties that are the result of local processes and not the advection of water from other sources. Hawk Channel appears to act as a “ditch”. It channels denser, high salinity water away from the reef. The CDOM from Florida Bay may have limited the penetration of UV light to the outer patch reefs in the past. The water does not reach the reef, at present, so the corals may be more vulnerable to bleaching. The high attenuation water at depth in Hawk Channel is opposite to the typical estuarine outflow of turbid water over oceanic waters.

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